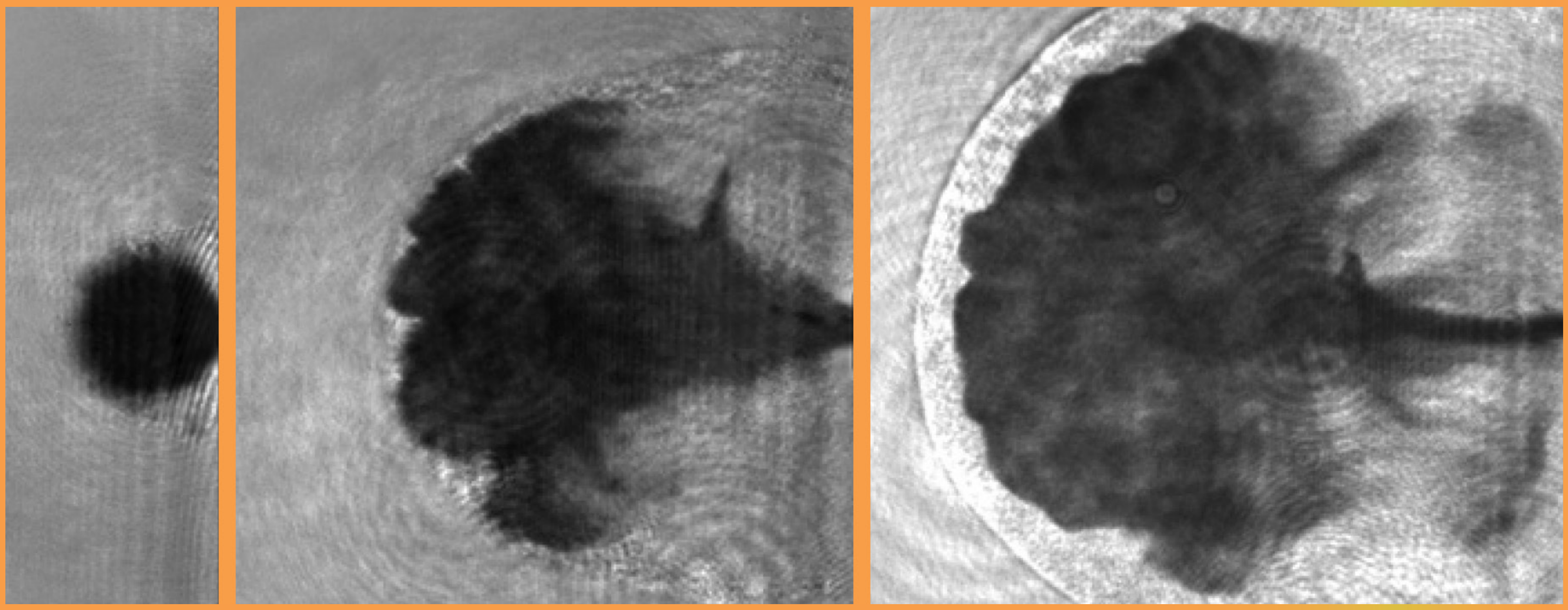
Science and Technology
UPDATE

January–March 2014

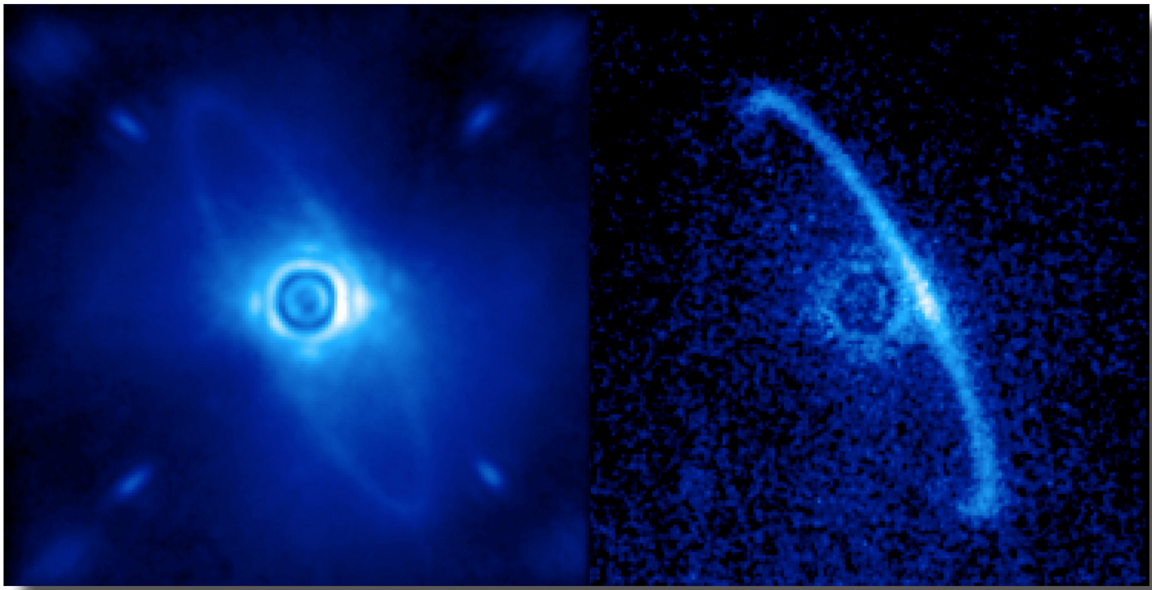


Science on a Mission

LLNL-MI-653447

FIRST IMAGES FROM GEMINI

The Gemini Planet Imager (**GPI**)—installed on the 8-meter **Gemini telescope** as the world's first fully optimized planet imager—recently saw first light, generating stunning images of far-away planets. Construction of GPI was led by Lawrence Livermore's Bruce Macintosh, who says, "Even these early first-light images are almost a factor of 10 better than the previous generation of instruments. In one minute, we were seeing planets that used to take us an hour to detect." The GPI can also see planets a million times fainter than their parent stars. In addition to leading the overall project, Livermore was also responsible for the GPI's **adaptive optics** system, which is the most advanced in the world. The Laboratory pioneered the field of adaptive optics for astronomy, which provides sharper images than is otherwise possible with Earthbound telescopes by dynamically compensating for turbulence in Earth's atmosphere. Adaptive optics were developed with early support from the **Laboratory Directed Research and Development Program**. The figure shows GPI first-light images, with normal light (left) and polarized light (right), of young star HR4796A, highlighting the disk of dust that orbits it.



RESEARCHER WINS PECASE

Livermore computational materials physicist Miguel Morales-Silva has been selected for one of the 102 Presidential Early Career Awards for Scientists and Engineers (PECASE) **announced by the White House** for 2014. Miguel's award recognized his research on first-principles descriptions of materials at high pressure and temperature using density functional theory and quantum Monte Carlo techniques. The PECASE awards, established by President Clinton in 1996, are the highest honor bestowed by the U.S. Government on science and engineering professionals in the early stages of independent research careers. Awardees are selected for their pursuit of innovative research at the frontiers of science and technology and their commitment to community service as demonstrated through scientific leadership, public education, or community outreach. The awardees for 2014 include 13 nominated by DOE.

About the Cover

Shadowgraphic images of expanding gaseous material ejected from a calcium fluoride surface during laser-induced damage. (See "Capturing the dynamics of ejected material during laser-induced damage," on page 16.)

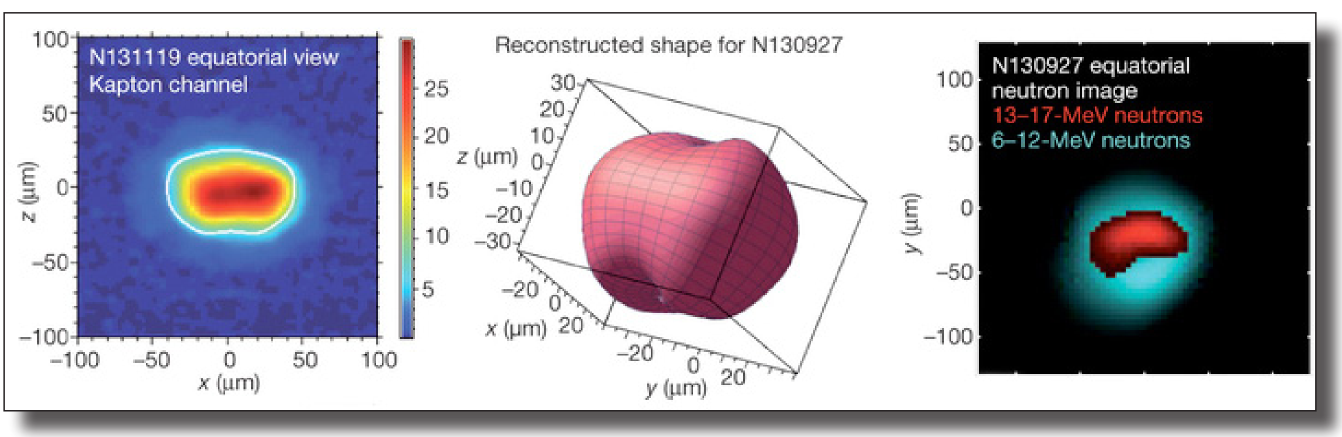
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-7NA27344.

NIF ACHIEVES WORLD'S FIRST-EVER FUEL GAIN—ANOTHER MILESTONE TOWARDS FUSION

Livermore researchers at the National Ignition Facility (**NIF**) recently achieved a key step along the path to fusion ignition—fuel gain, in which the energy generated through fusion reactions exceeds the amount of energy deposited by the drive lasers into the deuterium–tritium fuel. Reached for the first time on any facility anywhere in the world, this milestone achievement **is detailed in a paper published in the journal *Nature***. In the paper, LLNL's Omar Hurricane and colleagues report that fusion fuel gains exceeding unity were achieved in experiments using the "high-foot" implosion process developed at Livermore. The experiments also showed an order-of-magnitude improvement in yield performance over previous NIF shots as well as a significant contribution to the yield from alpha particle self-heating, in which the alpha particles (helium nuclei) produced in deuterium–tritium fusion deposit their energy into the fuel. This further heats the fuel and increases the rate of fusion reaction, producing more alpha particles in a "bootstrapping" process that accelerates the fusion rate to eventual self-sustaining fusion burn and ignition. The figure shows (left) an equatorial (side-on) view of the shape of the hotspot—where the laser energy is most concentrated in the fuel—in one of the experimental shots, (center) a three-dimensional reconstructions of the hotspot, and (right) the superposition of direct and down-scattered neutron images. The tight, roughly spherical shape of the hotspot was one of the keys to the researchers' success.

INVITED PRESENTATION AT AAAS ANNUAL MEETING FOCUSED ON NIF

Researcher **Narek Gharibyan** gave an invited presentation on radiochemical measurements of neutron capture and isomeric data acquired at the National Ignition Facility (NIF) at the American Association for the Advancement of Science (AAAS) **Annual Meeting, held February 12–17** in Chicago, IL. The neutron luminosity of a NIF implosion can produce measurable amounts of activation products from nanograms of target isotopes. Solid radiochemistry has recently been added as a new NIF diagnostic capability and is providing important insights into nuclear reactions in high-energy-density plasmas. Narek's presentation focused on initial results from the NIF Solid Radiochemistry diagnostic and was part of a **symposium** entitled "Stars in the Laboratory: Fundamental Nuclear Physics at the National Ignition Facility," organized by Chris Keane and Betsy Cantwell (both from LLNL) and Professor Ani Aprahamian (University of Notre Dame). Narek was also featured in a **roundtable discussion** entitled "What Would You Do with the World's Most Powerful Laser?" in which scientists discussed NIF's basic science potential and what experiments they would perform if they had the laser to themselves.



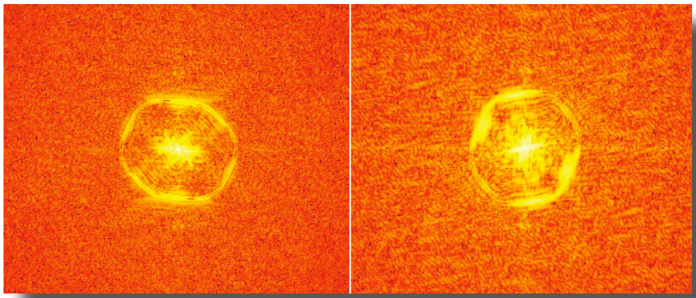
LIVERMORE ACHIEVEMENTS CITED IN *SCIENCE* OVERVIEW OF X-RAY CRYSTALLOGRAPHY OF BIOMOLECULES

In a special issue commemorating the **100th anniversary** of the important scientific technique of **crystallography**, *Science* magazine cites groundbreaking achievements by LLNL researchers in a review article on x-ray crystallography for determining the structure of large biological molecules. Three papers with Livermore authors are cited:

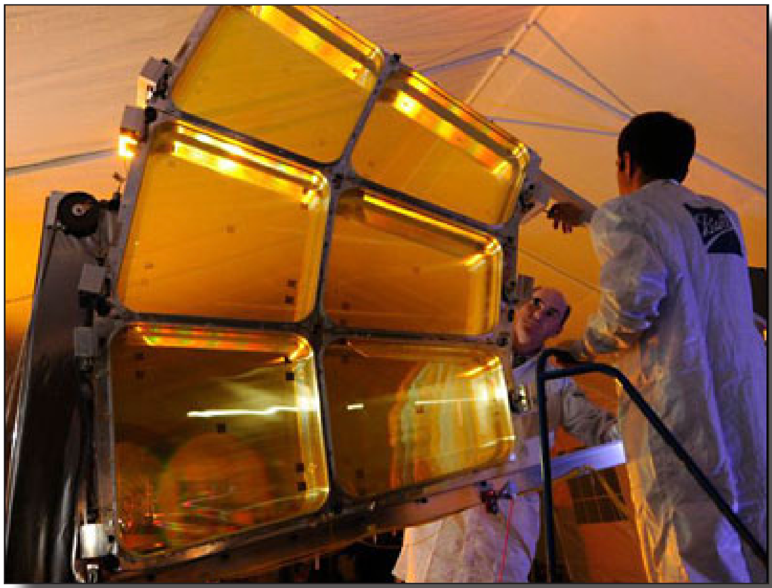
- "**Femtosecond x-ray protein nanocrystallography**"
- "**Natively inhibited *Trypanosoma brucei* cathepsin B structure determined by using an x-ray laser**"
- "**Single mimivirus particles intercepted and imaged with an x-ray laser**"

The Laboratory's Matthias Frank and Stefan Hau-Riege co-authored all three and two of the papers, respectively. In addition, authors Henry Chapman and Saša Bajt are former LLNL employees who conducted significant work in this field while at Lawrence Livermore, where, for instance, Henry's work was supported by the LDRD Program under the project "Biological Imaging with Fourth-Generation Light Sources" (**05-SI-003**).

For stories about recent Livermore achievements in crystallography, see pages **20** and **21** of this issue.



ULTRALIGHT SPACE OPTICS MADE WITH LLNL ETCHING TECHNOLOGY DEMO'D FOR DARPA



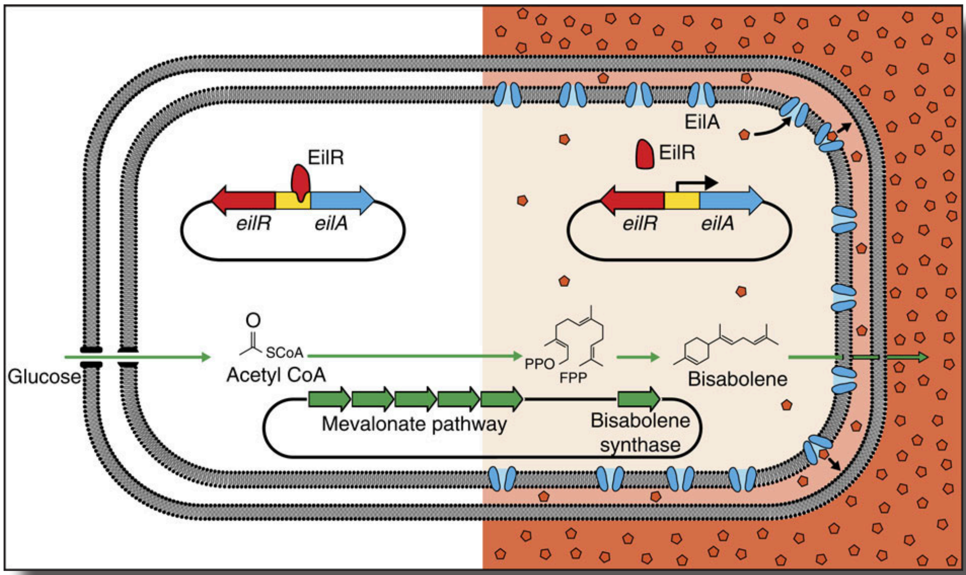
Etching technology developed at Lawrence Livermore was used to create optics for the Membrane Optic Imager Real-time Exploitation (**MOIRE**) program, whose progress **was recently demonstrated** to the Defense Advanced Research Projects Agency (DARPA), which leads the program. MOIRE would ultimately deploy a large, 20-m-diameter, space-based telescope in geosynchronous orbit and would use thin, lightweight Fresnel lenses instead of traditional glass mirrors or lenses to diffract light. The etching technology that made these thin-membrane lenses possible was developed by a group at LLNL led by **Jerry Britten** in the **National Ignition Facility**.

LABORATORY PARTNERS WITH STARTUP TO CONVERT NATURAL GAS TO LIQUID FUEL

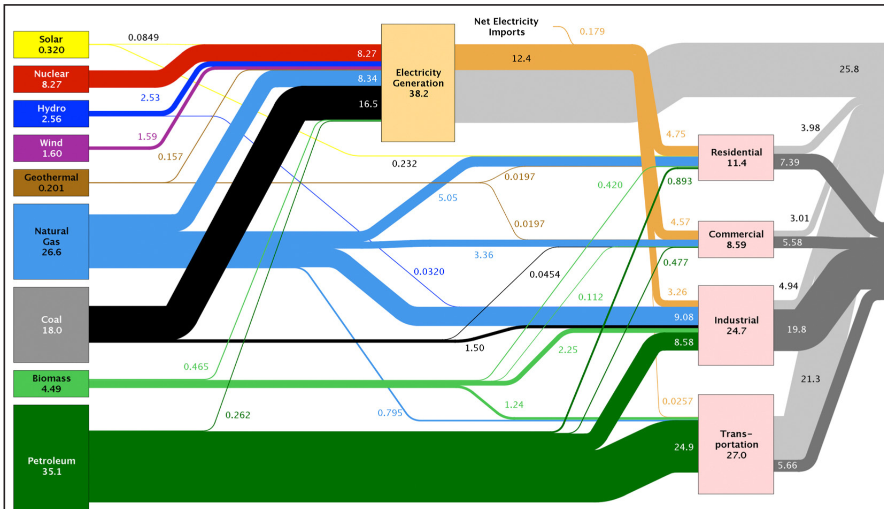
The Laboratory is collaborating with startup **Calysta Energy** on a new technology to convert natural gas from oil and gas operations—which might otherwise become pollution—to liquid methanol, which can either be used as fuel or converted to other useful chemicals. Bioengineered enzymes from Calysta are used as the catalyst for the conversion, while LLNL provides technical capabilities in nanostructures, reactor technology, and the 3-D printing of substrates containing the enzymes, which carry out the reactions with high selectivity under mild conditions. "With this technology, we would have a small portable reactor that would convert natural gas to a liquid fuel," said Lawrence Livermore engineer Joshuah Stolaroff, who co-leads the project with chemist **Sarah Baker** (right and left, respectiely, in photo). He adds: "If the technology works well, it could give the United States a new option for using our large reserves of natural gas." The work was supported by the Laboratory Directed Research and Development (**LDRD**) Program under a project headed by Sarah.

ENGINEERING BACTERIA WITH BIOFUEL-BOOSTING RESISTANCE

Scientists from Lawrence Livermore and the DOE's **Joint BioEnergy Institute** performed an interspecies transplant of bacterial genetic material that could improve the production of biofuels. **Publishing in *Nature Communications*, the team described** how they identified, in a soil microbe native to a Puerto Rican tropical rainforest, a pair of genes conferring resistance to ionic liquids and successfully spliced the genes into the genome of a strain of *E. coli* bacteria used to produce advanced biofuels. With this new genetic enhancement, the *E. coli* bacteria survived and even thrived in otherwise toxic concentrations of ionic liquids that are used as solvents to extract cellulose from biomass. The cellulose is then broken down into the sugars that the microbes use to make a terpene-based biofuel. Research is focused on this and other new liquid biofuels that "go beyond ethanol and can replace gasoline or diesel," said LLNL biochemist and team member **Michael Thelen**. In addition to eliminating a bottleneck in the production strategy for such biofuels, the work demonstrates how the adverse effects of ionic liquids can be turned into an advantage, by inhibiting the growth of other bacteria. In the figure, a **model** of the ionic-liquid-tolerant bacterium converting biomass into biofuel, narrow green arrows indicate the biofuel production pathway that begins with glucose on the left.



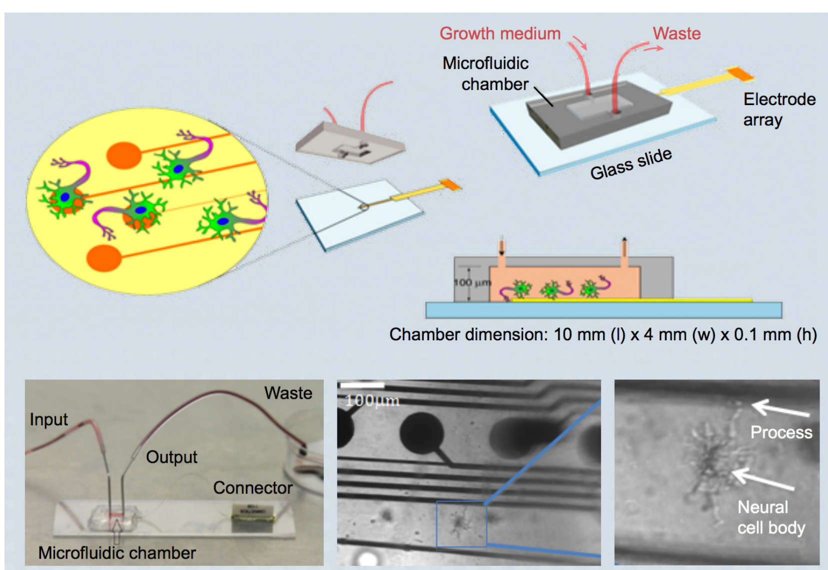
NEW ENERGY FLOWCHART GRAPHS INCREASE IN RENEWABLES, OVERALL ENERGY USE



The **latest version** of Lawrence Livermore's widely referenced flowcharts of energy use in the United States shows that the nation used more renewable, fossil, and nuclear energy in 2013. An increase in natural gas prices reversed a recent shift away from coal for electricity production, which also increased carbon dioxide emissions in 2013, the first such year-over-year increase since 2010, as shown in a **separate flowchart**. Nevertheless, says LLNL energy systems analyst A. J. Simon, "Gas plants are cheaper than coal plants. Natural gas is going to be a winner into the foreseeable future."

ADVANCES IN iCHIP, A HIGH-TECH ALTERNATIVE TO ANIMAL AND HUMAN TESTING

The In-vitro Chip-based Human Investigational Platform (**iCHIP**) team at LLNL recently announced two significant advances: demonstrating, for the first time, a primary human cell response to a surrogate chemical exposure on the iCHIP platform; and successfully culturing rat neurons on the device for three weeks—progress that will enable testing that involves long-term chronic exposure to low levels of chemicals. The iCHIP team of engineers, chemists, and biologists is creating a system that combines human cells, tissue engineering, and microfluidics to reproduce the human physiological response to neurological toxin. They have now made big strides in validating this integrated, physiologically relevant human model, which will eventually take animals out of testing and accelerate the development of new countermeasures. The iCHIP, which received critical **early-stage support from the LDRD Program**, is a low-cost alternative to animal trials and could minimize human trials by producing highly physiologically relevant data. The figure is an overview of the iCHIP platform and optical microscopy showing electrophysical stimulation of rat neuron cells.



KEN MOODY NAMED AAAS FELLOW

LLNL radiochemist Ken Moody **has been awarded** the distinction of fellow of the American Association for the Advancement of Science (AAAS). Ken, a 27-year Laboratory employee, has been a critical member of the team that discovered **six new elements**—113 through 118—among many other achievements. He was one of the 40 fellows elected in the chemistry category. Election as a fellow is an honor bestowed upon AAAS members by their peers to recognize distinguished efforts to advance science or its applications. This year, AAAS awarded 388 members with this honor. Ken and other new AAAS fellows were presented with an official certificate and a gold and blue rosette pin at the 2014 AAAS Annual Meeting, held in February in Chicago.

STEPHEN PAYNE ELECTED AS SPIE FELLOW

The Laboratory's **Stephen Payne** has been elected as **a fellow of SPIE**. Stephen, who is Program Element Leader for the Radiation Detectors Chemical Sciences Division, has a Ph.D. in physical chemistry from Princeton University. His research interests include radiation detectors (scintillators, semiconductors, gamma, and neutron), lasers materials, optics, basic physics, and chemistry.

DONA CRAWFORD SELECTED BY CALIFORNIA COUNCIL ON S&T

Dona Crawford, Livermore's Associate Director for **Computation**, has been named to the California Council on Science and Technology (**CCST**). An assembly of corporate CEOs, academics, scientists, and scholars, the CCST provides expert counsel on the science and technology issues facing California. "As an applied science laboratory," says Dona, "Livermore can both contribute to and benefit from the work of the CCST. By participating, we can build on our long-standing relationship with the state as a part of the University of California." She added: "Many of the challenges the state faces, such as energy, environment and cyber security, also are national concerns that are the focus of Livermore missions." Described as a state version of the national academies, the CCST was formed over 20 years ago as an independent body to advise the legislature and state agencies on technical issues. Dona was appointed for a three-year term, renewable for a second term.

COORDINATOR FOR U.S.–FRENCH STOCKPILE STEWARDSHIP COOPERATION SELECTED

Jason Burke has been named LLNL technical coordinator under an international agreement for cooperation in fundamental science supporting stockpile stewardship between DOE/NNSA and France's Commissariat a l'Energie (**CEA**). The goal of the agreement, which on the U.S. side encompasses LLNL as well as Sandia and Los Alamos National Laboratories, is to broadly encourage and facilitate basic science interactions in theoretical, computational, and experimental research and development

MORE RESEARCHERS JOIN DOE "WOMEN @ ENERGY" SHOWCASE

Women working at LLNL—including **Frances Alston** (photo), **Trish Damkroger**, and **Peg Folta**—continue to be chosen by DOE to be featured at **Women @ Energy**, an online showcase of women working in science, technology, engineering, and mathematics (STEM) at DOE laboratories, field sites, and headquarters. The site presents profiles and stories of women in STEM to showcase the mission-critical work that women are doing in STEM throughout DOE and offers role models for women and girls, who are critically underrepresented in these fields. The new additions will join their LLNL colleagues previously listed, such as **Diane Chinn** and **Dawn Shaughnessy**.

JENNIFER PETT-RIDGE ELECTED TO EMSL COMMITTEE

Jennifer Pett-Ridge, an environmental microbiologist at LLNL, has been elected to a 4-year term on User Executive Committee of the William R. Wiley Environmental Molecular Sciences Laboratory (**EMSL**). A scientific user facility located at the Pacific Northwest National Laboratory, EMSL is funded by DOE's Office of Biological and Environmental Research and provides integrated experimental and computational resources for discovery and innovation in the environmental molecular sciences. The User Executive Committee is an independent body charged with providing objective, timely advice and recommendations about the user experience to the leadership of EMSL. The Committee reports directly to the director of EMSL and serves as the official voice of the user community in its interactions with EMSL management. Jennifer will represent user science related to the EMSL **theme of terrestrial and subsurface ecosystems science**.

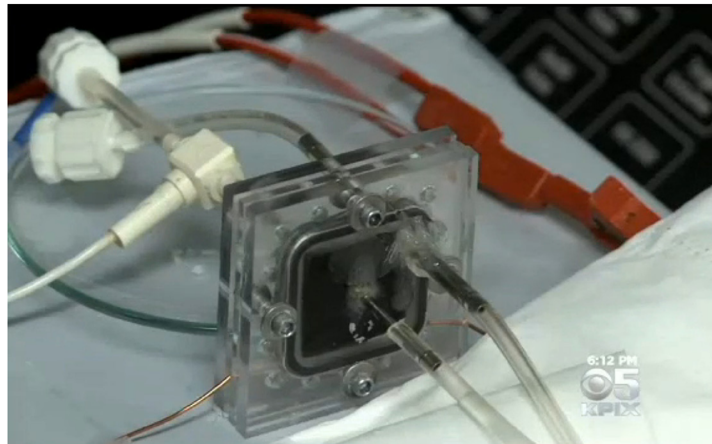
NEW DNA SEQUENCER MAKES IDENTIFYING MICROBIAL AGENTS EASIER AND CHEAPER

A team of Livermore scientists has delivered to a government sponsor the first fully automated analysis system for microbial forensics that is capable of handling both cultured ("pure") and highly complex clinical and environmental samples. The Microbial Threat Characterization Pipeline (MTCP), developed by Clinton Torres, Marisa Torres, Mark Wagner, and Jonathan Allen, allows scientists to perform next-generation DNA sequencing in the field, near the origin of samples, avoiding transport costs and other issues that often render samples useless. The MTCP uses the **Livermore Metagenomic Analysis Tool** and other LLNL-developed software. "This system leveraged software created over a period of six years by five different sponsors," said team leader **Tom Slezak**. "We have optimized the use of fast hardware, large memory, and clever algorithms to provide rapid but deep analyses, combined with a novel approach to present complex microbial analysis results along with confidence scores to yield actionable information. In addition to helping microbial forensics, MTCP has the potential to support DNA sequencing analysis in human health, global biosurveillance, BioWatch, and many other missions."

LAB HELPS BUILD HEX-ROTOR TECHOLOGY FOR UNMANNED AIRCRAFT

Lawrence Livermore is helping Naval Postgraduate School Research Associate Professor Kevin Jones (shown in photo) **develop a tethered hex-rotor aircraft for unmanned applications** in sensing and surveillance. The hex-rotor aircraft that Professor Jones is developing would be capable of extremely long-endurance operations and work in conjunction with sister aircraft to perform missions with very little human command and control. In the case of sensing and surveillance, his approach would overcome the power problem associated with rotary aircraft by offering a tethered alternative. "The challenge is to get a lot of power over a long skinny cable," said Jones.

WATER-DESALINATION TECHNOLOGY ON LOCAL NEWS



Lawrence Livermore's Michael Stadermann was **featured on an evening news segment** by local CBS affiliate KPIX in which he explains, in an interview at LLNL, the Laboratory's **capacitive deionization technology** for removing salts from water. If scaled up, this approach could provide a more cost- and energy-efficient method for purifying water than reverse osmosis, which is currently the dominant technology. The segment also mentions the Laboratory's plans to test the promising technology at a larger scale in Antioch, California. The photo shows a laboratory-scale version of the technology developed by Michael and team.

VEIN-IMAGING TECHNOLOGY LICENSED

This January, the Laboratory signed an exclusive patent license with **Near Infrared Imaging, Inc.** for an LLNL technology titled "Vein Imager and Non-Contact Optical Method for Detecting Ultrasound Waves for Vein Illumination and Optical Ultrasound Tomography." Near Infrared Imaging, a Wrentham, MA-based small business that already owns the trademark for Optical Ultrasound Tomography, plans to use the newly licensed technology in conjunction with others licensed from third parties to develop medical imaging products to **visualize veins** and to monitor the condition of other body functions.

LLNL Know-How in FEMA Chemical Response Report

LLNL scientists contributed a major deliverable to the Federal Emergency Management Agency (FEMA) for its document *Key Response Factors and Considerations for the Aftermath of a Catastrophic Chemical Incident*. LLNL researchers, led by **Sarah Chinn**, were funded by FEMA's **Chemical, Biological, Radiological, Nuclear, and Explosives Office** to develop the unclassified report, which informs responders and the general public on rare catastrophic chemical events. Specifically, LLNL used the best available science—models and simulations—to promote realistic planning, identify key response actions, and develop the basis for local planning efforts. Federal stakeholders were briefed on the results of three planning scenarios in Washington, D.C., in December.

LLMDA Proves Pathogen-Detecting Power in CDC Outbreak Analysis

The Centers for Disease Control and Prevention (CDC) recently used the Lawrence Livermore Microbial Detection Array (**LLMDA**) broad-spectrum pathogen microarray to test five blind samples from one of an outbreak of *Salmonella*. LLMDA correctly identified the species and strain of the bacterium in each case—a level of resolution unachievable with other existing assays. The CDC plans to continue evaluating LLMDA in future outbreak responses. In addition, LLMDA correctly identified three blind isolates from an international "unknown pathogen" exercise in tests performed by the CDC with analysis assistance from LLNL. The LLMDA team includes **Nick Be**, Shea Gardner, **Crystal Jaing**, Kevin McLoughlin, **Tom Slezak**, and Jimmy Thissen.

LLNL Camera Tech Inside DARPA "Eye in the Sky" Platform

Digital camera technology developed at LLNL was used inside an **imaging satellite platform that was successfully tested** as part of a Defense Advanced Research Projects Agency (DARPA) project. The Space Enabled Effects for Military Engagements (**SeeMe**) project would be an "eye in the sky" that provides imagery directly to troops in the field from a swarm of satellites in low Earth orbit. Livermore's **Vincent Riot** served as project engineer for LLNL's work with Millennium Space Systems, DARPA's contractor for SeeMe. Mike Scardera, the SeeMe project manager at Millennium said, "The detailed images we retrieved clearly demonstrate Lawrence Livermore's unique optics design is well suited for this size spacecraft, to provide high-quality space remote sensing."

Team Wins Funding for Algal Biofuel Research

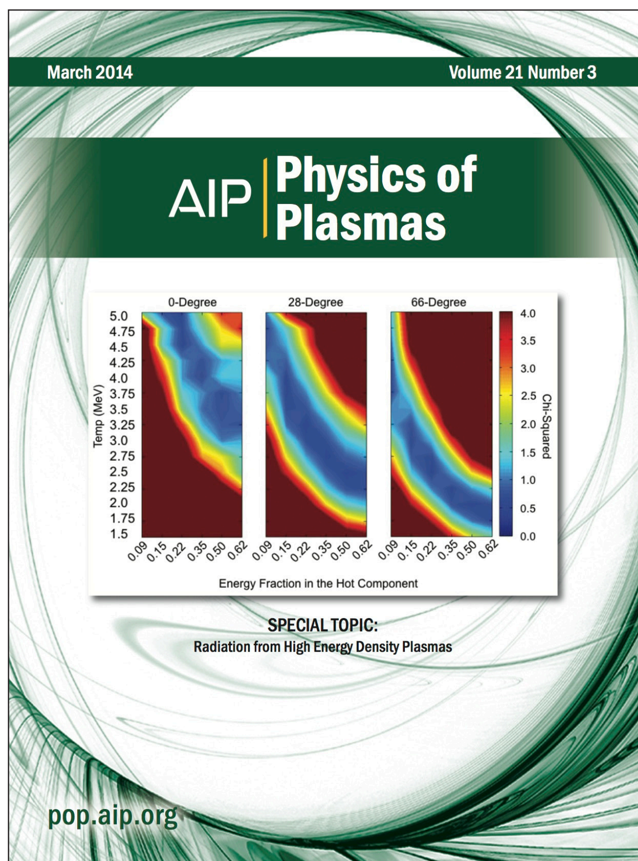
The DOE Office of Biological and Environmental Research (**BER**) has awarded Lawrence Livermore $1.5 million per year in new funding for research on the effect of bacteria–algae interactions on algal biofuel production. The project is a multidisciplinary, multi-institutional collaboration led by LLNL and involving Lawrence Berkeley, Sandia, and Pacific Northwest National Laboratories, as well as UCLA, NASA, and Stanford University. Competition for this funding, which will begin in fiscal 2015, was significant. BER requested five full proposals from an initial set of ten program plans (one per Laboratory), and all five of these finalists were reviewed at a reverse site visit in Washington, D.C., with LLNL being chosen as the sole awardee. Development of the proposal was led by Laboratory scientists Jennifer Pett-Ridge (see page **7**) and **Peter Weber**.

PAPER ON *NATURE* COVER LINKS OCEANIC NITROGEN INCREASE TO CLIMATE CHANGE

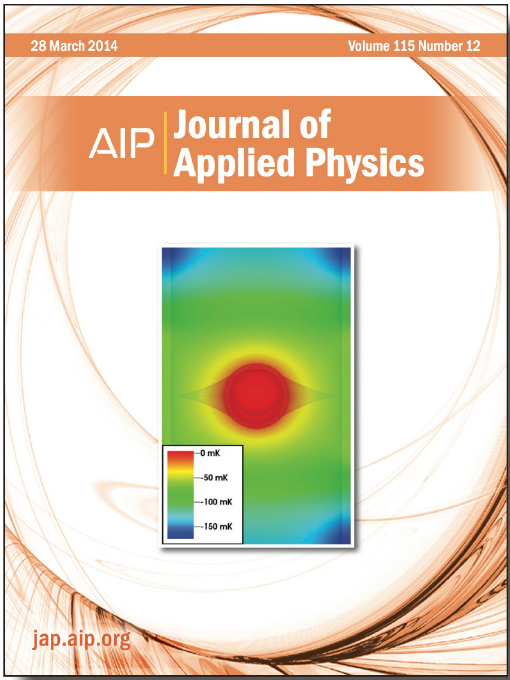
Lawrence Livermore scientist **Tom Guilderson**, working with colleagues at UC Santa Cruz, has determined that a long-term shift in nitrogen content in the Pacific Ocean has occurred as a result of climate change. The results, **featured on the cover of *Nature***, show an increase—still under way today—of 20% since the mid-1800s in overall nitrogen fixation in the North Pacific Ocean. The researchers uncovered this trend by examining nitrogen isotope ratios in corals in the world's largest contiguous ecosystem—the North Pacific subtropical ring of ocean currents. Because a coral reef can exist for thousands of years as new layers are created over old ones, the corals yield highly detailed records of changes in their environment going back millennia. This work also has significant implications about our understanding of effects of global warming in the Pacific and other subtropical regions.

FAST-ELECTRON EXPERIMENTATION ON COVER OF *PHYSICS OF PLASMAS*

In a **paper featured on the cover of *Physics of Plasmas***, a UC San Diego graduate student working with LLNL physicists Cliff Chen and other reports on the properties of fast electrons produced by a high-intensity, short-pulse laser interacting with matter under conditions relevant to fast ignition for inertial confinement fusion. In experiments at LLNL's **Jupiter Laser Facility**, the bremsstrahlung x-rays produced by these fast electrons were measured, allowing for model-dependent characterization of the fast-electron energy spectrum, angular distribution, and the conversion efficiency of laser energy. Monte Carlo simulations predicted the x-ray response of the target to the electron distributions; the temperature of the bremsstrahlung spectrum and the inferred electron spectrum were found to be angle dependent. Hybrid transport modeling of the distributions showed that self-generated fields can focus the electron beam.



THERMAL PROFILE OF HYDROGEN ISOTOPES ON COVER OF *JOURNAL OF APPLIED PHYSICS*



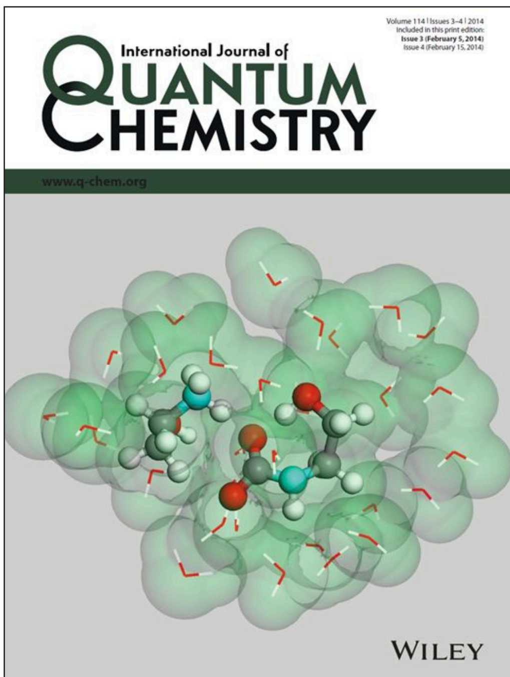
In a **paper featured on the cover of *Journal of Applied Physics***, Laboratory researchers including Salmaan Baxamusa describe the effects of self-heating and phase change on the thermal profile of hydrogen isotopes in confined geometries. In the growth of high-quality hydrogen layers in capsules for inertial-confinement fusion research, the in situ generation of single seed crystals is an important step. First, a polycrystalline solid layer is formed inside the shell and is slowly melted until a single crystal remains; this crystal is subsequently used as a seed for growing a solid hydrogen crystal from its melt. The team's detailed calculation of the thermal profile inside the shell shows that the minimum temperature on the shell's inner wall is initially at the mid-plane but that the accumulation of helium-3—a decay product of tritium—in the vapor phase causes a secondary temperature minimum at the top of the shell. The phenomena governing the behavior of this system are applicable to any confined multiphase system with a volumetric heat source. The results also highlight the importance of including the effects of phase changes even in systems that are closed to mass flow. Work at LLNL was supported by the **LDRD Program** under project **12-ERD-032**.

SIMULATIONS REVEAL NEW EFFECTS IN INTENSE LASER–SOLID INTERACTIONS

The high-energy-density plasmas produced by the interaction between intense laser light and solids are of fundamental interest for understanding warm-dense matter, plasma astrophysics, ion beams, and fast-ignition inertial confinement fusion. In a paper featured on the cover of *Physical Review Letters*, Laboratory researchers Frederic Perez and colleagues **report on three-dimensional particle-in-cell simulations** of the generation of fast electrons in a realistic oblique-incidence laser–target configuration. They find that the reflected light is intense enough to interact relativistically with the preplasma, creating currents and magnetic fields that compete with and eventually overcome the effects of the incident laser pulse. This has a significant impact on the angular distribution of laser-accelerated electrons; even a small deviation from normal incidence dramatically changes the fields, making them powerful enough to deflect megaelectronvolt-scale electrons. This effect, which had not been included in interpretations of previous experiments, is relevant to many important phenomena, such as understanding the interactions that will occur when the 200-terawatt laser upgrade at the **Matter in Extreme Conditions instrument** at the Linac Coherent Light Source becomes operational.

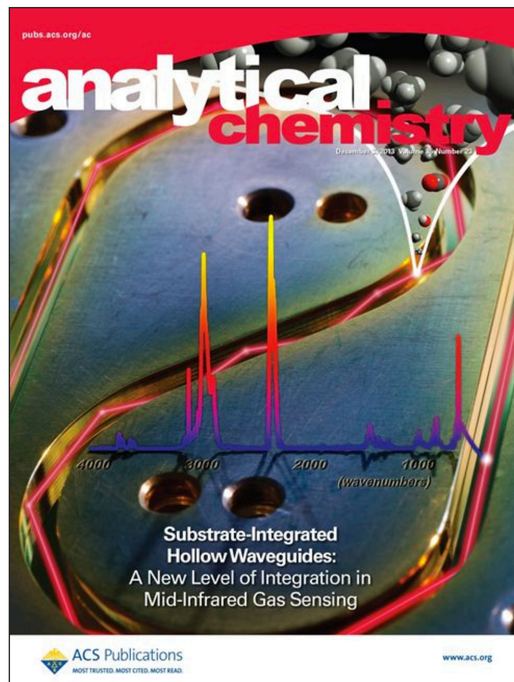
ATOMISTIC MODELING OF NEW CARBON-CAPTURE SYSTEMS

A paper by Laboratory physicist **Amitesh Maiti** on the use of atomistic modeling in developing high-efficiency carbon-capture systems is **featured on the inside cover of *International Journal of Quantum Chemistry***. High-priority carbon-capture efforts are aimed at large point-emission sources such as fossil-fuel-powered electrical generating stations, natural-gas-processing facilities, and various industrial plants. The importance and scale of these industrial activities make it essential to optimize any proposed capture process for speed, energy requirements, and cost efficiency. Amitesh reviews progress on novel materials for CO_2 capture, including liquid solvents such as amines, carbonates, and ionic liquids; microporous sorbents such as zeolites, activated carbon, and metal–organic frameworks; solid sorbents such as metal oxides and ionic clays; and polymeric and inorganic membrane separators. Each system is unique in its molecular-level interactions with CO_2, chemistry, heats of adsorption and desorption, and equilibrium thermodynamic and transport properties. The performance of any new material ultimately depends on basic chemistry and interactions at the atomic level, and molecular modeling therefore provides a powerful tool to accelerate the process of discovery, design, and screening of potential CO_2-capture materials.



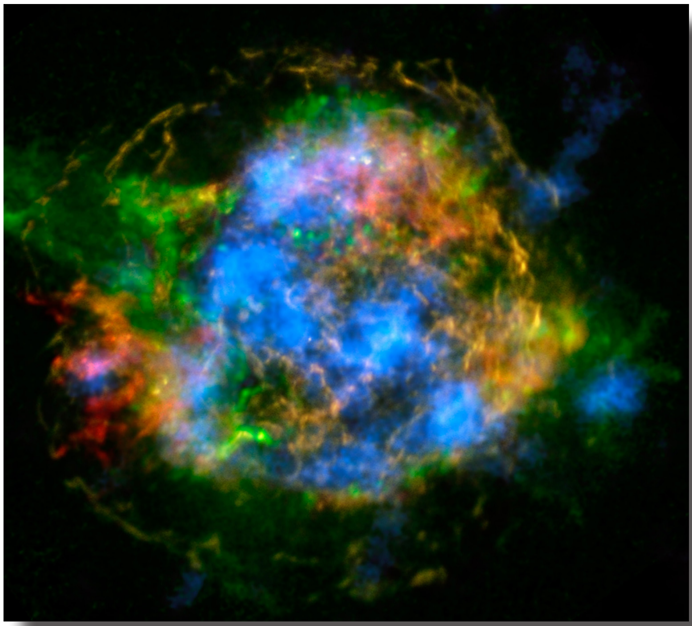
HOLLOW WAVEGUIDE WORK ON COVER OF *ANALYTICAL CHEMISTRY*

Research on substrate-integrated hollow waveguides conducted by LLNL researchers Chance Carter and coworkers, in collaboration with colleagues from the University of Ulm, Germany, was featured on the cover of *Analytical Chemistry*. The team reports fabricating and testing a new generation of unprecedentedly compact hollow-waveguide gas cells. The cell uses small sample volumes and is suitable for a variety of broad- and narrow-band mid-infrared sensing applications, such as industrial process measurements, environmental monitoring, and clinical diagnostics, including breath analysis. Substrate-integrated hollow waveguides are layered structures with light-guiding channels integrated into a solid-state substrate material. The devices are competitive in performance with conventional leaky-mode fiberoptic silica hollow waveguides with similar optical path lengths but offer greater flexibility in design and permit a broad variety of manufacturing strategies, substrate materials, and optical coatings, resulting in greater robustness, compactness, and cost-effectiveness. These advantages, combined with the unmatched modularity of this novel approach, allow substrate-integrated hollow waveguides to be tailored to almost any kind of gas sensor technology, providing adaptability to the demands of a wide range of sensing needs.



NuSTAR HELPS EXPLAIN HOW STARS GO SUPERNOVA

Using observations from NASA's Nuclear Spectroscopic Telescope Array (**NuSTAR**), an international team of astrophysicists **describe in *Nature* how stars blow up in supernova explosions**. The team, including LLNL's Michael Pivovaroff and William Craig (now at LBNL), used NuSTAR to map x-ray emissions from the decay of titanium-44, a short-lived radioactive isotope produced in supernovae, in the supernova remnant Cassiopeia A. The findings reveal how shock waves likely rip massive dying stars apart in the explosions, which expel much or all

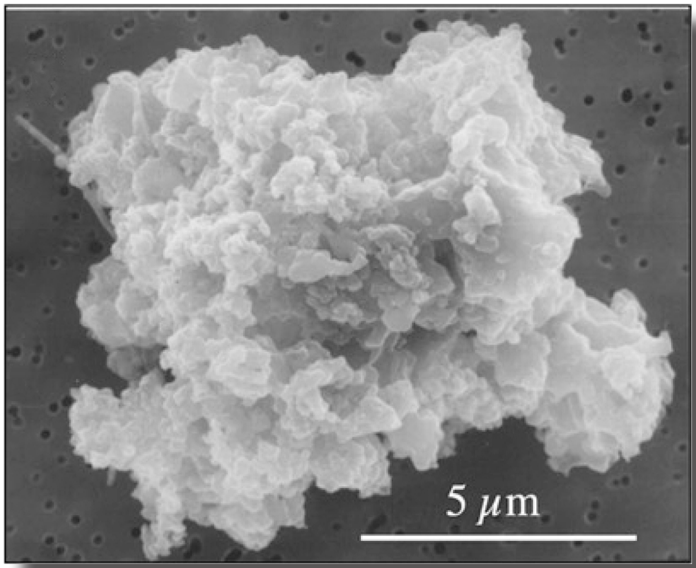


of a star's material at high velocities, driving a shock wave into the surrounding interstellar medium. This shock wave sweeps up an expanding shell of gas and dust called a supernova remnant. Although stars are spherical balls of gas, their explosions are not simple uniform spherical expansions. The new NuSTAR observations confirm that the Cassiopeia A's explosion was not smoothly spherical and suggest that the inner regions of the star were undergoing large-scale convective motions before detonation. Important optics design and testing work for NuSTAR was done at LLNL, where this x-ray-focusing technology dates back to the LDRD-supported High Energy Focusing Telescope (**HEFT**) instrument, the success of which allowed Livermore to propose NuSTAR to NASA. In the image of Cassiopeia A, titanium-44 data obtained with NuSTAR is shown in blue and is combined with previous data obtained with the **Chandra X-ray Observatory** showing iron (red) and silicon and magnesium (green).

DETECTOR FINDS PLAGUE IN ANCIENT HUMAN REMAINS

In **a paper published in *Scientific Reports*** (*Nature*'s new online, open-access journal covering all areas of the natural sciences), researchers from LLNL, McMaster University, the College of Physicians of Philadelphia, and the University of South Carolina document their use of the Lawrence Livermore Microbial Detection Array (**LLMDA**) to identify human bacterial pathogens from archeological remains. The team tested two samples previously verified as containing pathogens through other technologies. In one sample, from a patient who died during an 1849 cholera outbreak in Philadelphia, the LLMDA identified the presence of *Vibrio cholerae* (the cholera bacterium). The detector also verified the presence of *Yersinia pestis* (the bacterium that causes the plague) in a tooth from a victim of the Black Death in London in 1348, helping researching conclude, for instance, that this instance of the plague was **likely spread by airborne infection**, not by a rat-flea vector as had been long theorized. The LLMDA technology proved itself tenfold faster and tenfold less expensive than using current genomic sequencing methods for studying pathogens in ancient DNA. The results, say the authors, demonstrate "that the LLMDA can identify primary and/or co-infecting bacterial pathogens in ancient samples, thereby serving as a rapid and inexpensive paleopathological screening tool to study health across both space and time." Developed in early 2008, the LLMDA permits the detection within 24 hours of any virus or bacteria that has been sequenced and included in the instrument's 135,000 probes and so has myriad applications in healthcare, biodefense, and other fields. Early development of the LLMDA was funded by the **LDRD Program**.

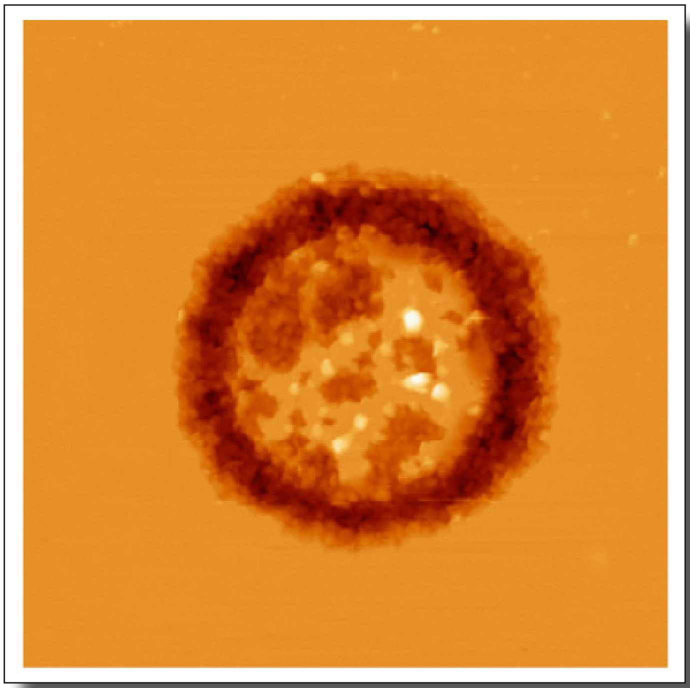
WATER IN "STARDUST" HAS IMPLICATIONS FOR ORIGINS OF LIFE IN THE UNIVERSE



Lawrence Livermore scientists John Bradley and Hope Ishii, now at the University of Hawaii at Manoa, report in *Proceedings of the National Academy of Sciences* that **solar wind radiolysis—"space weathering"—produces water on interplanetary dust particles**. They used electron microscopy and valence electron energy-loss spectroscopy to detect water in vesicles in space-weathered rims on the particles collected by **NASA's *Stardust* mission**, concluding that the water-filled vesicles form from the reaction between hydrogen ions in the solar wind and oxygen in the rims. Because this mechanism of water formation almost certainly occurs in other planetary systems, these findings have potential implications for the origin of life. For instance, the mechanism could predict the formation of water on airless bodies such as the Moon and asteroids, the delivery of water to the surfaces of planets, and the production of water in other astrophysical environments. In the case of terrestrial planets such as early Earth, water and organic carbon were likely delivered simultaneously by large amounts of incoming interplanetary dust particles. Early work on microscopic analysis of such particles **was funded by the Laboratory's LDRD Program**. The figure is a secondary electron image of one of the interplanetary dust particles examined.

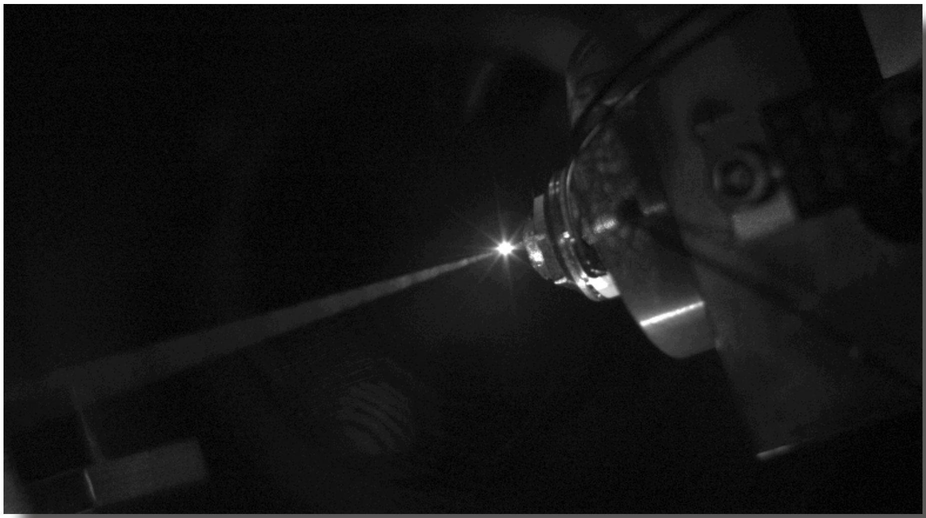
"NATIVE" LASER DAMAGE PRECURSORS DESCRIBED

In a paper in *Optics Express*, LLNL researchers Nan Shen, Jeff Bude, and Christopher Carr report the results of experiments designed to improve understanding of the role of damage precursors in the optics of high-fluence laser systems such as the National Ignition Facility. Although contaminants and inclusions are important sources of damage in many cases, surface damage on high-quality optics is typically dominated by other sources, all of which lie either on or within a few hundred nanometers of the surface. These are referred to as "native" surface precursors and damage sites. In their study, the researchers created artificial absorbers on fused silica optics to investigate precursor properties critical for native surface damage initiation. They demonstrated that strong adhesion between absorbers and silica is necessary for the launch of an absorption front and subsequent damage initiation. "With careful design of further experiments," they write, "we hope to learn more about the properties of native damage precursors on the surface of silica optics such as size, density, and method of deposition which cause them to be damage-prone." The figure is an atomic force microscopy image of an annealed disc after laser irradiation.



LASER EXPERIMENTS PROVIDE INSIGHT INTO GIANT GAS PLANETS —AND FUSION IMPLOSIONS

Lawrence Livermore researchers were part of a team that used the Vacuum Ultraviolet Free-Electron Laser at Deutsches Elektronen-Synchrotron (DESY) in Germany to create the same conditions found in the lower atmospheric layers of giant gas planets such as Jupiter or Saturn. Their findings—**published in *Physical Review Letters***—reveal how liquid hydrogen becomes a plasma and provide information on the material's thermal conductivity and its internal energy exchange, which are important ingredients for planetary models. The scientists laser-heated liquid hydrogen almost instantaneously, from minus 253 to around 12,000 degrees Celsius, creating a plasma of electrons and protons. Says LLNL physicist and paper co-author Tilo Doeppner, "The equilibration time [i.e., the time required for protons and electrons to achieve thermal equilibrium] is directly related to the thermal and electrical conductivities, which are crucial parameters to correctly simulate the massive, outward-directed heat flows in giant gas planets and subsequently their radial temperature profiles." An accurate knowledge of the conductivity of hydrogen also is crucial for correctly modeling the ablator–fuel interface in inertial confinement fusion capsule implosions at LLNL's National Ignition Facility. The DESY experiments "were an important stepping stone, since they showed us how to advance our understanding of high-energy-density plasmas with free-electron x-ray lasers," Tilo said. Work at Livermore was supported by the LDRD Program, specifically **project 11-ERD-050**, "Dynamics of Ultrafast Heated Matter." The figure shows a hydrogen jet source producing 18-micrometer droplets for nearly instantaneously heating at DESY.



OPTIMIZED BERYLLIUM NIF CAPSULE DESIGN DEBUTED

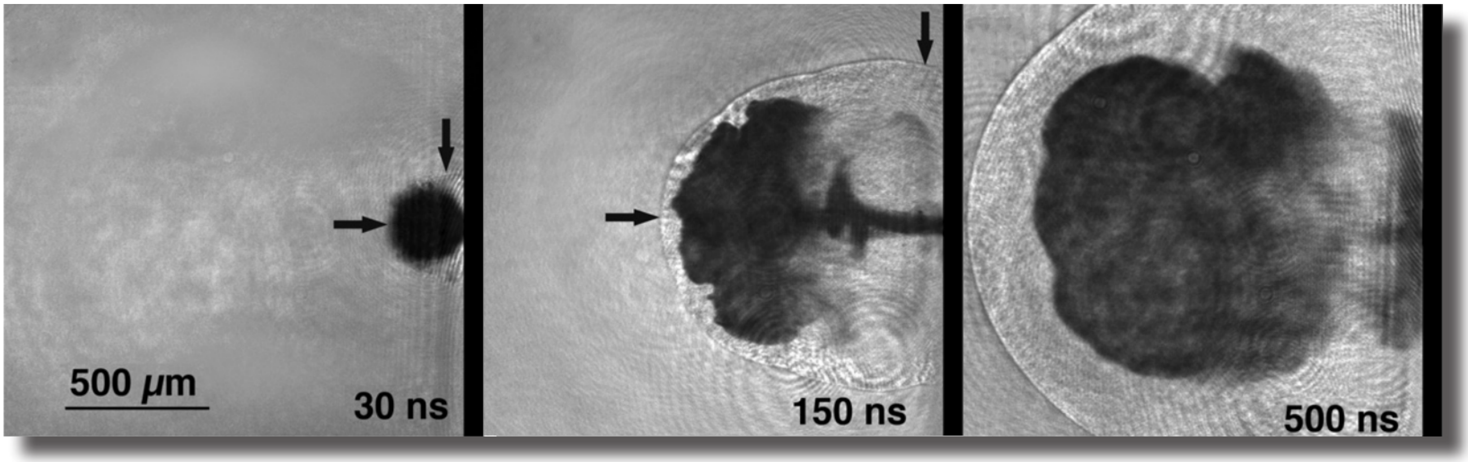
Target capsules (ablators) in NIF experiments to date have been made of germanium or silicon-doped plastic or undoped, diamondlike high-density carbon. Beryllium is believed to present a more attractive option for ablator materials. The element's low opacity and relatively high density may lead to higher rocket efficiencies, giving a higher fuel implosion velocity for a given x-ray drive, and to higher ablation velocities, providing more ablative stabilization and reducing the effect of hydrodynamic instabilities on implosion performance. These advantages would enable a larger target design optimization space and could significantly improve the NIF ignition margin. In a ***Physics of Plasmas* paper**, researchers at Livermore and LANL present an optimized beryllium ignition target design for four-shock, design-performance NIF laser shots that takes advantage of knowledge gained from recent NIF experiments, including more realistic levels of laser–plasma energy backscatter, degraded hohlraum–capsule coupling, and the presence of cross-beam energy transfer.

CAPTURING THE DYNAMICS OF EJECTED MATERIAL DURING LASER-INDUCED DAMAGE

In a **paper published in *Applied Physics Letters***, LLNL researchers Stavros Demos, Raluca Negres, and Alexander Rubenchik reported on studies of the gaseous material ejected during laser-induced damage on the output surface of calcium fluoride (CaF_2). The researchers found that under typical operational conditions of high-power lasers at ambient conditions, the gaseous material does not expand beyond about two millimeters from the surface. A nonsymmetric expansion of the shockwave at early probe delay times can be attributed to the pistonlike compression of the surrounding air by the directionally expanding gaseous plume behind it. A backflow observed after the initial expansion leads to exposure of the cold surface to the hot ejected gaseous material, causing re-condensation and material deposition. It also can cause a change in the trajectory of microscopic ejected particles, depending on their size and speed as well as the backflow speed. This backflow can cause contamination of the surface, which then can act as a source of additional damage initiation and growth. The results also suggest that the material ejection is prolonged, extending more than 300 nanoseconds after termination of the laser pulse. The figures are shadowgraphic images of expansion of the ejected gaseous material in CaF_2 at laser probe delay times of from 30 to 500 nanoseconds. Arrows indicate the position of the shockwave in the axial and lateral directions.

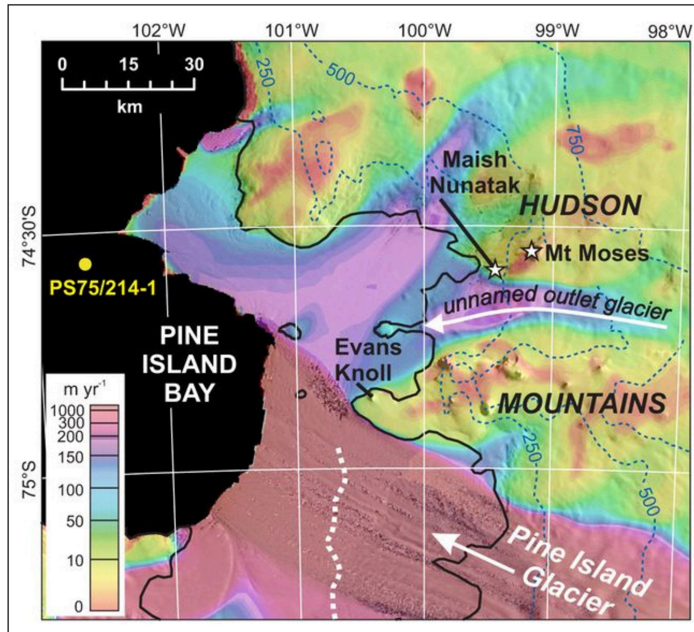
PHASE STABILITY OF TRANSITION METALS SHOWN AT HIGH TEMPERATURES AND PRESSURES

A team of LLNL scientists recently concluded a study of the phase stability of vanadium metal and vanadium–chromium alloys at high temperatures and pressures, **publishing their results in *Physical Review B***. Alexander Landa, Per Söderlind, and Lin Yang had predicted nine years ago that the cubic phase of vanadium becomes mechanically unstable during compression because of the intraband nesting of the electronic Fermi surface. Although the occurrence of such nesting in vanadium is widely acknowledged, it was thought that elevated temperatures would wash out the instability of the cubic phase and make the rhombohedral phase unstable. However, using self-consistent ab initio lattice dynamics in conjunction with density functional theory, the LLNL team **demonstrated that the pressure-induced mechanical instability of the body-centered-cubic vanadium metal persists at elevated temperatures**, contrary to previous thinking. The team also found that the addition of chromium to vanadium decreases the temperature at which stabilization of the body-centered-cubic phase occurs at elevated pressure. **Supported by the Laboratory's LDRD Program**, this work has important implications for the strength of metals relevant to LLNL's national security mission.



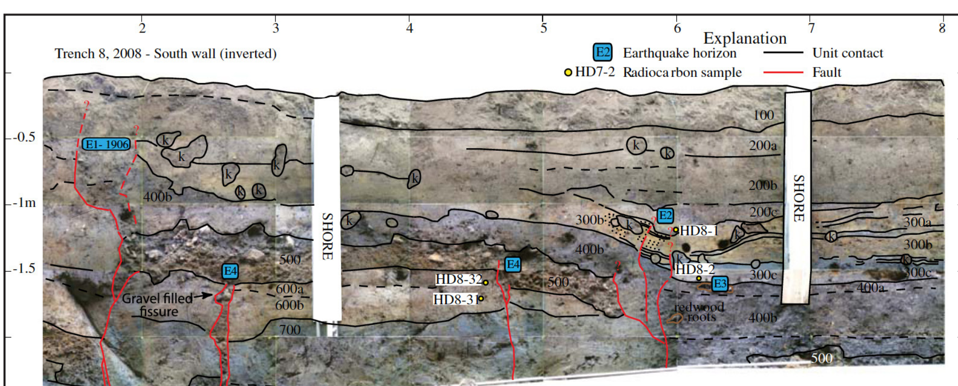
GLACIER MELT RATE COULD PERSIST FOR DECADES OR EVEN CENTURIES

Antarctica's Pine Island Glacier has been undergoing rapid melting and retreating for the past two decades, but new research by an international team, including researchers from LLNL, shows that this same glacier also experienced rapid thinning about 8,000 years ago. By measuring the concentration of beryllium-10, a short-lived radionuclide produced by cosmic rays impinging on rocks, LLNL **Center for Accelerator Mass Spectrometry** researchers Bob Finkel and Dylan Rood showed that the melting 8,000 years ago lasted for decades to centuries, at an average rate of more than 100 centimeters per year, which is comparable to modern-day melting rates. These findings indicate that modern-day melting and thinning could last for several more decades or even centuries. This work **appeared in the online edition of *Science***. The figure shows flow velocities of the Pine Island Glacier and an unnamed outlet glacier flowing through the Hudson Mountains.



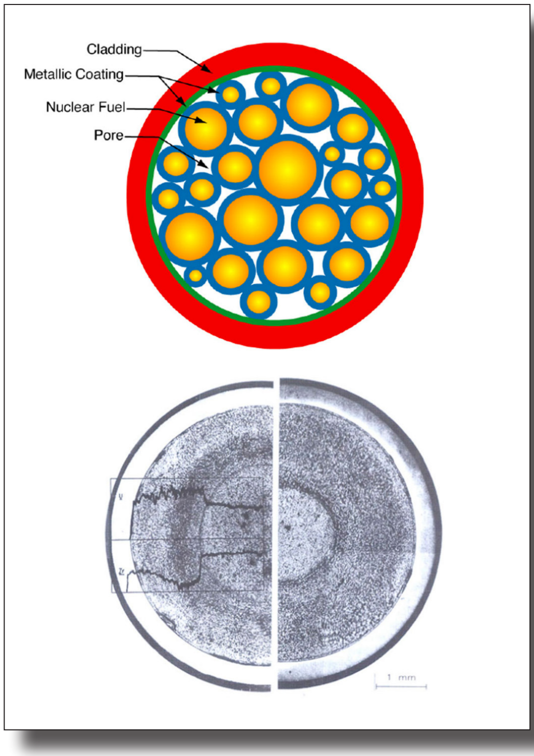
LAB CARBON DATING AIDS SAN ANDREAS FAULT RESEARCH

The radiocarbon dating by Livermore's Center for Accelerator Mass Spectrometry (**CAMS**) of redwood chips and stumps left behind by 19th century treecutters working in the Santa Cruz Mountains helped researchers forensically reconstruct historic seismic activity along the San Andreas fault. The organic evidence was found in trenches dug through fault areas—buried there, the researchers believe, by the historic earthquakes that also produced the fissures and other geologic features they found. Consequently, determining the wood's age—which is possible with a high degree of certainty with CAMS technology—helped narrow down exactly when those earthquakes occurred. These findings, made by researchers from the University of Oregon and the California Geological Survey, were **published in the *Bulletin of the Seismological Society of America*** and also **reported in the San Francisco *Chronicle***. The figure is a photomosaicked image of a trench wall showing the displacements that indicated past quakes and the locations where the wood chips were found.



MODELLING SPENT NUCLEAR FUELS AS A POTENTIAL ENERGY SOURCE

Lawrence Livermore scientists have modeled actinide-based alloys, such as those in spent nuclear fuel, in an effort to predict how evolving fuel chemistry impacts material performance for such applications as reusing spent nuclear fuel as an energy source. The new approach—developed under an LDRD project titled "**Ultrahigh-Burn-up Nuclear Fuels**"—can predict important features in phase diagrams, namely phases and their stability in composition–temperature domains and microstructures, and guide further experiments to enable modeling of materials performance at higher scale, according to Patrice Turchi, lead author of a **review paper appearing in the *Journal of the Minerals, Metals & Materials Society***. This work addresses a critical gap in our knowledge about actinides that relates to an important part of America's energy strategy: preserving nuclear fuel resources by minimizing fuel waste. Today, only a fraction of the enriched uranium used in U.S. civilian reactors is actually converted to fission energy; the remaining spent nuclear fuel (SNF) therefore contains considerable potential energy in the form of uranium-238, but a roadblock to "breeding" plutonium from this uranium is lack of knowledge about the highly complex interaction of the materials in SNF. The Livermore team, which consists of **Patrice**, **Per Soderlind**, and **Alexander Landa**, developed thermodynamic modeling of the complex, multicomponent actinide-based alloys with input from state-of-the-art ab initio electronic structure energetics. This systematic modeling is crucial to developing fuel from SNF because it can identify trends in fuel behavior and predict how fuel chemistry impacts swelling, resistance to irradiation, fission gas management, and thermal properties. "This is an 'ideal to real' strategy for the development of the next generations of advanced nuclear energy systems," Patrice said. The figure shows (top) a schematic representation of an inert metal matrix fuel and (bottom) an example of site redistribution in uranium–zirconium fuel at 10% peak burnup.

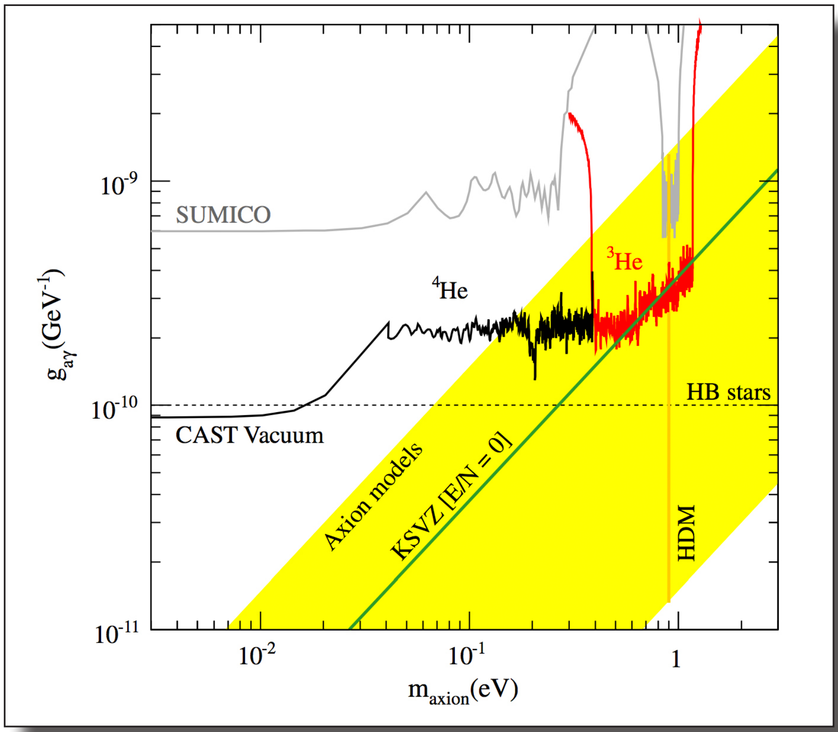


CORROSION MECHANISM OF PROMISING SOLAR-TO-HYDROGEN CONVERTER ELUCIDATED

Semiconductor compounds that combine a group III element with a group V element (known as III-V semiconductors) are used as photocathodes and have the highest solar-to-hydrogen conversion efficiency, giving them excellent potential for tapping alternative energy sources. However, these semiconductors undergo rapid photocorrosion in water, which greatly limits their practicality for actual marketable products. An LLNL team led by **Brandon Wood** and including postdoctoral researcher **Wooni Choi** has conducted molecular dynamics simulations of this corrosion, showing, in **a paper published in *Journal of Physical Chemistry C***, that a monolayer of oxygen on the surface dramatically changes the potential energy profile of water dissociation and facilitates proton transport through a hydrogen bond network. This finding indicates that it may be possible to tune and optimize this electrode–electrolyte interface for catalytic hydrogen evolution and protection against corrosion.

AXION COLLABORATION PUBLISHES MORE-STRINGENT LIMITS ON PARTICLE PROPERTIES

Culminating a six-year-long experimental campaign, the CERN Axion Solar Telescope (**CAST**) collaboration has **published new constraints on the mass of the axion particle** in *Physical Review Letters*. The search covers the mass range from 0.64 to 1.17 eV and closes the gap between previous CAST data and the cosmological hot dark matter limit. Notably, the new results exclude extremely important parts of the quantum chromodynamics parameter space, in which the existence of axions are postulated to resolve the apparent lack of charge conjugation parity (CP) symmetry violation (the "strong CP problem"). Axions could also be a form of cold dark matter and would have been produced in the early universe. The hypothetical particles would also be produced in the hot interiors of stars—including our own Sun—and it is these axions for which CAST searches. LLNL is one of the few institutions in the world involved with both leading axion experiments, the other being the **Axion Dark Matter Experiment**, which is investigating the lower mass part of axion parameter space. Livermore's involvement in the CAST collaboration was initiated and supported by funding from the LDRD Program (specifically, projects 04-ERD-032, **09-ERD-052**, and **10-SI-015**). The figure shows the exclusion region achieved by CAST and others, with the new CAST results in red and the yellow band representing typical theoretical models.



NEW METHOD TO PROBE NATURE OF DARK ENERGY

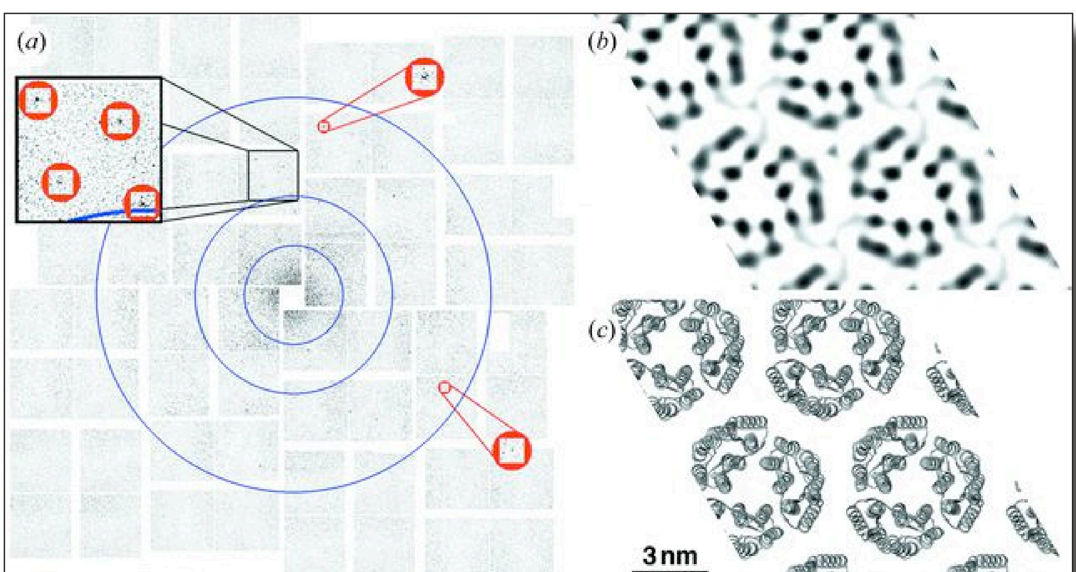
Current astronomical surveys have imaged millions of galaxies over hundreds of square degrees of the sky. The Large Synoptic Survey Telescope (LSST), now under construction, will image the distribution of billions of galaxies over half the celestial sphere. We know that galaxies are clustered in a "cosmic web," but the images of galaxies we observe are also modified by gravitational lensing by intervening mass along our lines of sight. Even with the LSST, observational errors and limitations will make it difficult to distinguish between these two important physical contributions to the observable distribution of galaxies. Publishing in *Physical Review Letters*, LLNL physicist Michael Schneider **shows the clustering and gravitational lensing magnification** of galaxies can be unambiguously and optimally disentangled using basic information about the distances of the galaxies from us. Detected 10 years ago, the lensing magnification of galaxy images was until now considered too weak to be a competitive way to constrain cosmology, but the new LLNL-developed algorithms promise to make galaxy lensing magnification a new, independent method to measure dark-energy properties. This work, which was supported by the LDRD Program, opens yet another direction of exploration for the LSST and other dark-energy experiments.

NEW TECHNIQUE IMAGES PROTEINS PREVIOUSLY INACCESSIBLE TO X-RAY CRYSTALLOGRAPHY

For the first time, two-dimensional (2-D) protein crystals have been studied at room temperature with x-rays, using a new x-ray diffraction technique that could open the door for scientists to learn more about membrane proteins, an important category that constitutes about one-third of all human proteins. The scientists **report their findings in the *International Union of Crystallography Journal***. The team, led by Livermore's Matthias Frank and also including researchers at UC Davis, the University of Hamburg, and elsewhere, used the Linac Coherent Light Source, whose x-rays are bright and fast enough to image the structure of crystallized membrane protein molecules only a single layer thick. These proteins are not amenable to conventional x-ray crystallography because of the difficulty of growing them in three dimensions. "Our work," said Matthias, "demonstrates for the first time that two-dimensional protein x-ray crystallography is a potential method for obtaining protein structure information." The figure shows (a) background-subtracted diffraction pattern for 2-D crystals of the protein streptavidin, (b) a 2-D electron density projection map, and (c) a ribbon diagram created using the known crystal structure, symmetry, and unit cell for comparison with (b).

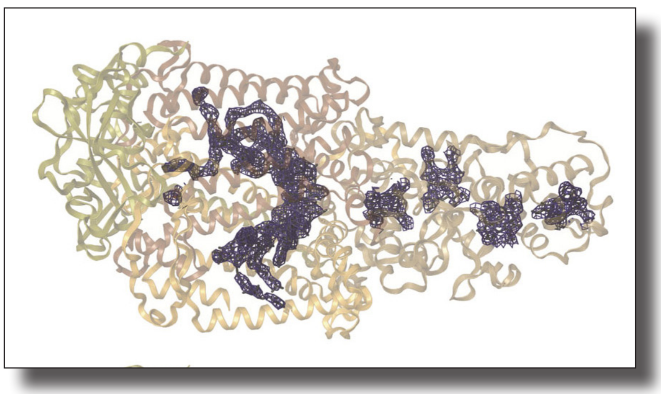
MAGNETIC SPIN CONFIRMED IN PLUTONIUM–GALLIUM ALLOYS

An LLNL team lead by Per Söderlind and Alexander Landa, who have studied plutonium–gallium alloys for more than a decade, have confirmed and explained the magnetic spin of the alloy by applying first-principle electronic structure calculations. The results were **published in *Journal of Nuclear Materials***. A model previously developed by Russian experimentalists showed that anti-ferromagnetism cannot exist in unalloyed (pure) face-centered-cubic plutonium, but this new study reveals that the addition of small amounts of gallium actually stabilizes the anti-ferromagnetic configuration. "Magnetism (including anti-ferromagnetism) has been debated in the literature for years, so it's important that our theoretical model supports the recent magnetization experiments," Per said. The properties of plutonium–gallium alloys, particularly its stability and phase diagram, have been studied experimentally and theoretically for years by LLNL scientists because of their relevance for the material properties of plutonium as well as their importance for fundamental understanding of electron correlation in plutonium.



FEMTOSECOND CRYSTALLOGRAPHY SETS RECORD FOR MEMBRANE-PROTEIN RESOLUTION

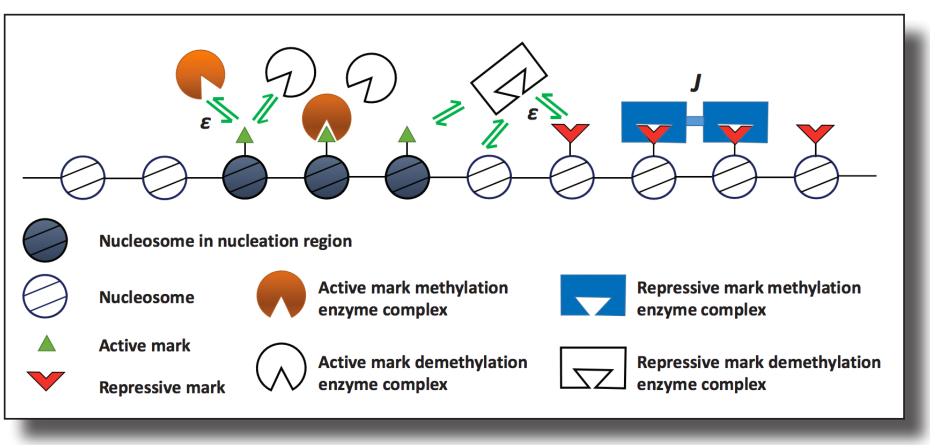
Many important proteins, such as those found in cell membranes, do not readily form large crystals suitable for structure determination by traditional x-ray diffraction methods. Even serial femtosecond crystallography (SFX), a new crystal-structure determination method that makes use of the intense photon beams available at x-ray free-electron lasers (XFELs), had achieved only limited resolution with membrane proteins—only 5.7 Å, not enough to resolve side chains on the protein. However, an international team including LLNL scientists Mathias Frank and Mark Hunter **reports, in *Nature*, a resolution of 3.5 Å achieved with SFX analysis** of a membrane protein. Microcrystals of a membrane protein complex from the photosynthetic reaction center of a purple photosynthetic bacterium were injected into the focused XFEL beam of the Linac Coherent Light Source, and diffraction data from 1,175 individual crystals were merged to determine the structure.



Revealing protein side chains, cofactors, and bound lipid molecules, the results demonstrate the great potential of XFEL-based SFX for the challenging field of membrane protein structural biology. LLNL's participation in this work was funded by the LDRD Program and the **UC Lab Fees Research Program**. The figure is an electron-density view in which all cofactors (highlighted in dark color) are revealed after structural refinement to 3.5-Å resolution.

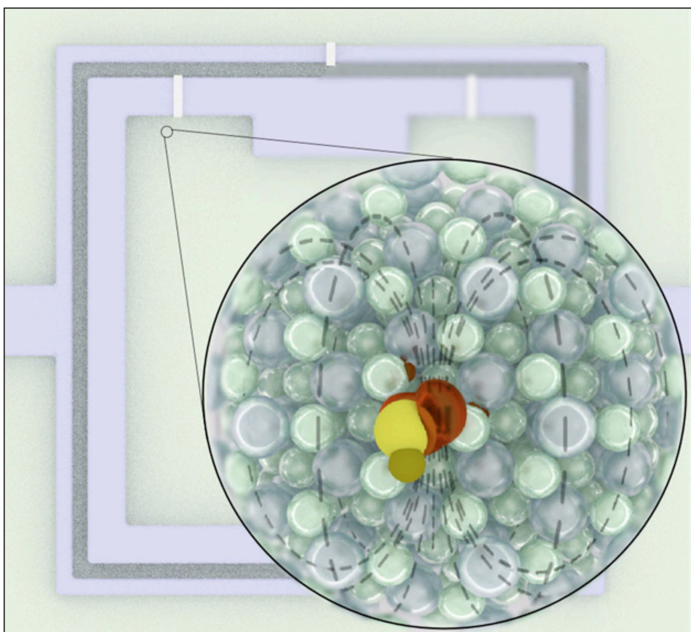
MODEL DESCRIBES MECHANISM OF EPIGENETIC MEMORY

Livermore physicist Ken Kim and colleagues have used statistical mechanics and mathematical modeling to shed light on the mechanism of epigenetic memory—how an organism can create a "biological memory" of some event that does not reside in its actual genes. Epigenetic modifications, while essential in the development and function of cells, also play a key role in cancer. "For example," says Ken's colleague and former LLNL postdoc Jianhua Xing, now at Virginia Tech, "changes in the epigenome can lead to the activation or deactivation of signaling pathways that can lead to tumor formation." Using tools often used in physics research, the team constructed a mathematical model that captures the essential features of epigenetic memory revolving around modifications to histones, a type of protein. **Published in *Physical Review Letters***, the work "highlights the interdisciplinary nature of modern molecular biology," said Ken. The figure is a schematic illustration of the model, where ε denotes enzyme binding energy, and J denotes enzyme lateral interaction energy.



NEW INSIGHT INTO PERFORMANCE-LIMITING NOISE IN QUANTUM COMPUTING QUBITS

LLNL postdoc **Donghwa Lee**, working with Vincenzo Lordi and Jonathan DuBois, have discovered an important source of decoherence noise affecting the usability of superconducting circuits as quantum bits (qubits) for quantum computers. In **a paper appearing—and featured as an "Editors' Suggestion—in *Physical Review Letters***, they report that for sapphire substrates, imperfect surface termination related to adsorption of chemical species from the atmosphere or the fabrication process can produce states that contribute to decoherence. In particular, a sapphire surface readily adsorbs water molecules from the atmosphere, which can be detrimental to the



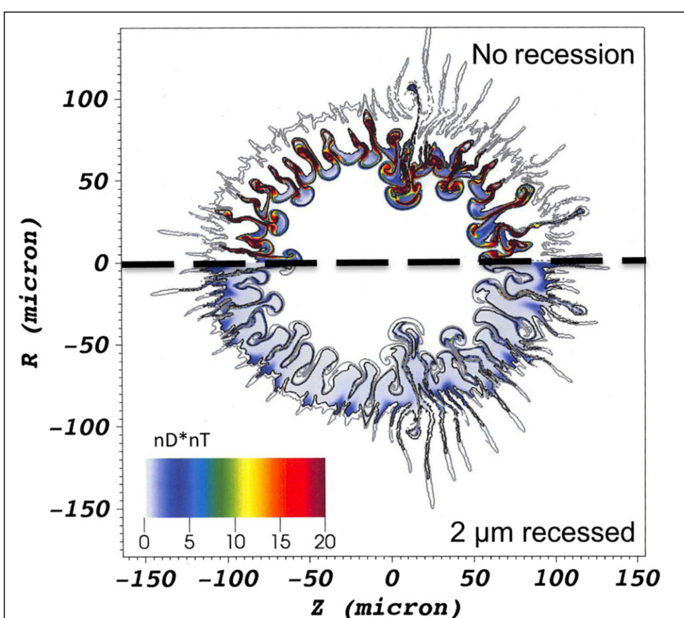
device's performance. This discovery was made using first-principles simulations of the magnetic properties of the sapphire surface when exposed to dozens of different molecular adsorbates. Using a computational materials design approach, the team identified possible ways to render the surface both physically and magnetically stable, such as exposing the surface to strongly bonding molecular species that do not introduce paramagnetism or inducing surface electron accumulation with an electric field. Support for this work was **provided by the Laboratory's LDRD Program**. The figure shows a hydroxyl adsorbate from ambient water vapor on the surface of the sapphire substrate used to fabricate this superconducting qubit, as it leads to spin localization (red isosurface) and local paramagnetism (shown by the magnetic field lines), producing decoherence noise.

PROPOSED WATCHMAN NEUTRINO DETECTOR HIGHLIGHTED IN *APS NEWS*

An LLNL-led effort to develop a large-scale, water-based anti-neutrino detector for both nuclear security and basic science applications—the WATer CHerenkov Monitor of AntiNeutrinos (WATCHMAN) Collaboration—was **featured in the American Physical Society (APS) website *APS News***. The national security application for WATCHMAN is to determine whether a nuclear reactor up to 400 kilometers away is producing plutonium for nuclear weapons. If successful, WATCHMAN could make it nearly impossible for countries to hide illicit plutonium production. It would also mark the first use of neutrinos in a practical application. All nuclear reactors emit antineutrinos, and although other forms of reactor-produced radiation are blocked by a few feet of soil or concrete, antineutrinos can travel essentially unimpeded through the entire Earth, making it impossible to shield the antineutrino signal or to hide it except by placing another reactor nearby. As currently proposed, the project would be funded by both the DOE National Nuclear Security Administration and the DOE Office of Science. A final decision from the Office of Science will come sometime after May, when the Particle Physics Project Prioritization Panel delivers its final recommendations.

MEASUREMENTS OF ABLATOR–GAS ATOMIC MIX IN NIF IMPLOSIONS

The first results from an experimental campaign designed to measure the signature of an atomic ablator–gas mix in capsule implosions on NIF, improve the ability to model this mix in 2D simulations, and assess the importance of atomic mix to yield degradation **were reported in *Physical Review Letters***. In the experiments, capsules containing layers of deuterated plastic placed at various offsets from the inner surface of the shell were filled with high-purity tritium gas; the shell–gas mix was studied by measuring the deuterium–tritium (D–T) neutron yield and ion temperature. As the reactants were initially separated during implosion, the D–T fusion yield provided a direct measure of the atomic mix of ablator into the hot spot gas. While the tritium–tritium fusion reaction probed conditions in the core of the implosion hot spot, the D–T reaction probed a mixed region on the outer part of the hot spot near the ablator–hot spot interface. The results suggest that low-mode hydrodynamic instabilities were the primary sources of yield degradation, with the ablator–gas mix playing a secondary role. Based on these results, the ignition program has moved toward mitigating instability growth and the seeds of these low-mode modulations in future ignition designs. The figure shows the product of the deuterium and tritium number densities (n_D and n_T) for simulations with layers recessed by 0 micrometer (top) and 2.27 micrometers (bottom), indicating spatial distribution of the shell–gas mix at the interface.



NIF SHOCK TIMING IN *PHYSICS OF PLASMAS*

Recent advances in shock timing experiments and analysis of cryogenic deuterium–tritium (D–T) ice layered capsule implosions at the National Ignition Facility (NIF) provide a new capability for capsule-centric assessment of the effects of hot-electron preheating on DT ice layers. The **results are reported in a *Physics of Plasmas* paper** comparing experimental results with simulations, showing good agreement for the timing of the first three shocks in four-shock D–T ice layered implosions but a considerable discrepancy in the timing of the fourth shock, which was attributable to electron preheat. The Velocity Interferometer System for Any Reflector (VISAR) data and analysis techniques add to the experimental constraints and may alter the previous understanding of implosion behavior. The results also suggest promising directions for improvement of implosion performance. Recent implosion experiments performed in near-vacuum hohlraums, for example, effectively eliminate stimulated Raman scattering instability and consequently remove this component of hot-electron preheat. Lead author Harry Robey was joined by LLNL colleagues and collaborators from the University of Rochester and General Atomics.

PLANARIZATION TO INCREASE DAMAGE RESISTANCE OF LASER MIRRORS

A newly developed planarization process can increase the resistance of laser mirror coatings to damage from infrared laser light by as much as a factor of 20, LLNL researchers and collaborators **report in an invited *Applied Optics* paper**. The researchers say substrate nodular defects in optical interference mirror coatings can behave as micro-lenses, intensifying laser light into the defect structure. Depositing a thick planarization layer, however, effectively smoothes over the defect, after which a nearly defect-free multilayer can be deposited on the nearly planar surface. The process developed for the study consists of depositing a 50-nanometer-thick silica layer, etching away half of the deposited layer with an ion beam, and repeating the process until the desired level of planarization is achieved. This substrate defect planarization was shown to increase the laser resistance of infrared mirror coatings to greater than 100 joules per square centimeter—an increase of twentyfold over previous techniques—when tested with 10-nanosecond infrared laser pulses.

Faster, More Efficient Groundwater Studies with New Noble Gas Measurement Method

A team led by Lawrence Livermore postdoc **Ate Visser** developed a membrane inlet mass spectrometry system for measuring noble gases in gas and water samples in real time. The team **published their results in *Rapid Communications in Mass Spectrometry***. Noble gases dissolved in groundwater can be examined to reveal such information as paleoclimate, water recharge conditions, and subsurface travel times. Conventionally, noble gas samples are cumbersome to collect and analyze, requiring noble gas purification, cryogenic separation, and static mass spectrometry. This created the need for a quicker and more efficient sample analysis method. The new system developed is sufficiently accurate and precise to enable studies of groundwater flow at managed aquifer recharge facilities that use introduced noble gas as a tracer, delivering an accuracy comparable with that of traditional noble gas mass spectrometers for argon, krypton, xenon while reducing the time required to make a noble gas measurement by a factor of 10. The team also included researchers from the International Atomic Energy Agency and California State University–East Bay.

Volcanoes Helped Slow Planet Warming: Study

The subject of **a new paper appearing in *Nature Geoscience*** is how volcanoes have helped offset the warming of Earth driven by greenhouse gases. Sufficiently large volcanic eruptions inject sulfur dioxide into the stratosphere, where the gas forms droplets of sulfuric acid—"volcanic aerosol"—that reflect some incoming sunlight, thereby cooling the troposphere below. This phenomenon, the authors say, explains what is known in climate science as the "warming hiatus," in which Earth's troposphere has since 1998 exhibited relatively little warming despite rising levels of greenhouse gases in the atmosphere. This hiatus is, the paper posits, due to a string of volcanic eruptions beginning around that time. "In the last decade, the amount of volcanic aerosol in the stratosphere has increased," explains LLNL's **Ben Santer**, lead author of the study, "so more sunlight is being reflected back into space." In what co-author **Susan Soloman** called "the most comprehensive observational evaluation of the role of volcanic activity on climate in the early part of the 21st century," the team performed statistical analysis indicating significant correlations between volcanic aerosol observations and satellite-based estimates of lower tropospheric temperatures, as well as the sunlight reflected back to space by the aerosol particles.

Carbon Nanotubes Could Help with Tissue Healing and Repair

Former Lawrence Fellow **Nadeen Chahine** and colleagues from LLNL and UC Davis recently published in *Tissue Engineering Part A* **the results of a study of the long-term biocompatibility of single-wall carbon nanotubes** (SWNTs) for use in the tissue engineering of articular cartilage. The team hypothesized that a suitably treated SWNT nanocomposite matrix would provide an improved substrate for chondrocyte growth and cartilage production. (Chondrocytes are the cells that produce and maintain healthy cartilage.) Their results indicated that chondrocytes tolerate functionalized SWNTs well, with minimal evidence of cell toxicity. Tissues containing

SWNTs and treated so their surfaces were covered with carboxyl molecular groups exhibited improved biomechanical properties over control tissues. These results suggest that SWNTs have a unique potential for cartilage tissue engineering, in which functionalization with bioactive molecules could provide an improved substrate to stimulate cellular growth and repair. Other LLNL authors of the paper include Nicole Collette, Cynthia Thomas, and Gabriella Loots. Work at LLNL was supported by the LDRD Program, specifically project **09-LW-072**, “Effect of Aging on Chondrocyte Function.”

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